CHAPTER 3

HF ANTENNA PERFORMANCE

Antenna performance is controlled or influenced by a number of factors. Orientation, polarization and radiation pattern must be considered along with ground plane requirements, feed systems, siting and separation criteria, real estate requirements, and ground constants and conductivity. All of these factors must be considered carefully in order to attain optimum antenna performance in ship/shore/ship, broadcast, ground/air/ground, and point-to-point HF communications systems.

3.1 ORIENTATION AND POLARIZATION

Orientation and polarization requirements vary with the antenna application, and may be different for ship/shore/ship, broadcast, ground/air/ground, and point-to-point communications.

3.1.1 Ship/Shore/Ship and Broadcast Communications

Ship/shore/ship and broadcast HF communications requirements are usually fulfilled by vertically polarized, omnidirectional or sector antennas. Sky-wave propagation is ineffective, generally, for short-range communications because of skip distance associated with this mode of transmission. However, at the low end of the HF band, ground-wave propagation from vertical antennas can be quite reliable within the sky-wave skip distance and beyond, depending upon the ground constants of the path. Vertically polarized ground waves are particularly effective over sea water, and substantial distances can be spanned reliably with operating frequencies up to approximately 5 MHz. There are numerous vertically polarized antennas that are suitable for ship/shore/ship and broadcast HF communications. Those most commonly used for Navy service are discussed in chapter 4.

Although vertical antennas are used for most ship/shore/ship applications, very long distances between terminals may be spanned more effectively by sky-wave propagation. In these circumstances, horizontally polarized antennas such as horizontal LPA's (fixed azimuth or rotatable) and rhombics are normally used.

3.1.2 Ground/Air/Ground Communications

Omnidirectional, broadband HF antennas are essential for effective ground/air/ground communications since aircraft operate at varying distances, bearings and elevation angles from ground terminals, and because numerous and rapid frequency changes are required to maintain reliable communications as the position of the aircraft changes.

Vertically polarized omnidirectional antennas are generally well suited to the propagation requirements of ground/air/ground communications. HF sleeve antennas have been in use for some time in ground/air/ground systems; however, conical monopoles and

inverted cones are being installed as programmed replacements for the sleeve antennas because they possess broader bandwidth characteristics than the sleeve antenna.

A greater degree of reliability for ground terminal reception of relatively low power aircraft signals, particularly teleprinter or other digital data transmissions, may be achieved through some type of diversity operation. Unfortunately, the real estate constraints at the receiving location may make space diversity reception impractical. Likewise, frequency diversity transmission from aircraft is generally precluded because of space and equipment limitations in the aircraft. Polarization diversity, however, can be employed by the ground terminal to provide improved signal reception. This type of diversity operation is made possible by using omnidirectional, horizontally polarized antennas in conjunction with vertically polarized antennas. The HF quadrant antenna illustrated in figure 4-28, is one type of horizontally polarized antenna that possesses the omnidirectional broadband qualities necessary for use in conjunction with a vertical antenna in a polarization diversity system.

3.1.3 Point-to-Point Communications

The most commonly used HF antennas for point-to-point communications are horizontally polarized. Usually rhombics and horizontal LPA's are specified since they provide the necessary bandwidth, gain, directivity and reliability for long-distance communications. Their relatively low radiation angle and low ground losses make them well suited to the performance objectives for long distance service. Vertical LPA's are sometimes used for long-distance point-to-point communications, but satisfactory results in this application depend upon the use of a ground plane radial system to keep the radiation angle low.

3.2 ANTENNA RADIATION CHARACTERISTICS

Gain, bandwidth, useful radiation angle and VSWR are major performance factors to be considered along with orientation and polarization. Radiation characteristics, including patterns of several types of antennas, are presented in chapter 4. In addition, typical radiation performance characteristics are included in the Antenna Characteristics Chart, foldout 5-1.

3.3 ANTENNA GROUND PLANE

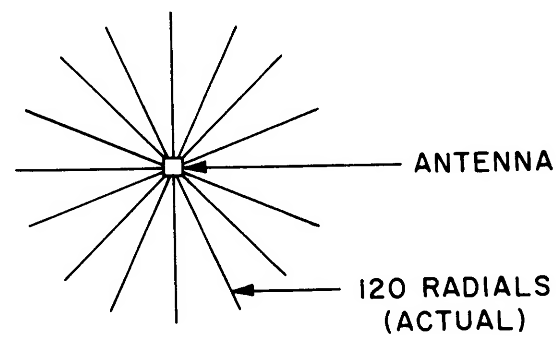
A ground plane is required for any ground-mounted antenna if the antenna is fed in a manner that makes the earth the return path for current flow. An arrangement of wires comprising a ground plane improves antenna radiation efficiency and provides an improved low-loss path for the return current.

Conical monopoles, discones, inverted cones, sleeves and some vertical LPA's are typical of the antennas requiring ground planes.

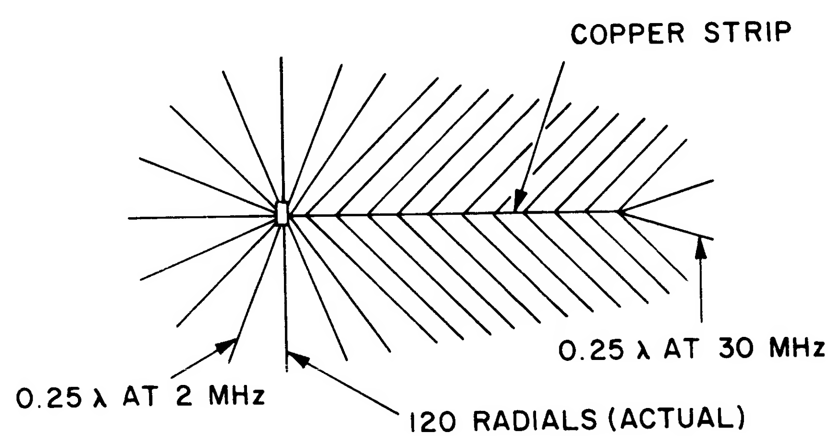
Ground planes can be considered in three basic categories: radial grounds, ground mats and counterpoises.

3.3.1 Radial Ground Plane

A radial ground plane is generally considered the most effective grounding configuration for vertical antennas. It is constructed of radial wires originating from a point at the base of the antenna as shown in figure 3-1A. In this case 120 equally distributed radial wires that are at least one-quarter wavelength long at the lowest design frequency are normally used. When a vertically polarized LPA is used the 120 radials are placed in the configuration shown in figure 3-1B. The length of the ground radials for the LPA vary smoothly from at least one-quarter wavelength at the lowest design frequency to one-quarter wavelength at the highest design frequency.



A. TOP VIEW OF ANTENNA AND RADIALS LEADING OUTWARD



B. PLAN VIEW OF TYPICAL GROUND PLANE FOR VERTICAL LOG PERIODIC ANTENNA

Figure 3-1. HF Antenna Radial Plane Ground Systems

Ground radial kits are supplied as standard items with some vertical antennas; e.g., conical monopoles, inverted cones, and vertical monopole LPA's. General specifications for ground radial materials and installation are as follows:

a. Ground radial wires should be at least one-quarter wavelength long at the lowest design frequency of the antenna. The gauge of the radial wires need only be sufficient to withstand the mechanical stresses of installation. Usually No. 8 or No. 10 AWG annealed copper-clad steel wire is adequate. To increase the ground plane the lengths of the radials should be increased rather than the wire cross-sectional area.

b. Ground radials are most effective when installed on the earth's surface. However, radial wires are normally buried in order to ensure physical protection. The depth of burial varies with frequency and should conform to the following rules:

(1) Frequency $\leq$ 9 MHz - burial depth $\leq$ 6 inches.

(2) Frequency > 9 MHz - burial depth $\leq$ 3 inches.

c. Where terrain or boundary conditions prohibit the desired radial length, connection of each radial to a ground rod is recommended, provided that the rods can be driven at least 3 feet into the ground. Ideally, the rods should be set 10 feet into the earth's surface for maximum effectiveness at most antenna locations. However, the depth of refusal may be so shallow that even the 3-foot depth is not feasible. If such is the case, it will probably be necessary to accept something less than an ideal ground plane.

Peripheral bonding of the radial wires to a closed loop of wire that surrounds the ground plane is recommended, whether ground rods are used or not. Silver soldering, brazing, and exothermic welding are acceptable methods of bonding.

When ground rods are not used, the radial wires should be staked as necessary to ensure physical stability.

d. On installations where location of adjacent antennas can cause ground radials to cross each other, interference may be generated by non-linear junctions formed where the radials overlap. If this condition exists, the following alternatives may be followed as best suited to the particular application:

(1) Bond radials at their crossing points.

(2) Use insulated wire for the radials or insulate the wires at the crossing points.

(3) Substitute a copper mesh ground mat for the radial ground plane. The dimensions of the mesh mat should be determined on an individual case basis.

(4) Bury the ground radials of the affected antennas at different depths at the intersecting points, keeping the higher frequency antenna's radials nearest the surface.

3.3.2 Ground Mat

When high antenna-base currents are present, a copper mesh ground mat is required at the antenna base to further insure against ground system power loss. A typical mat is 12 feet square and is fabricated from expanded copper or from copper wires bonded together to form a grid. Installation practices are the same as those specified for ground radial systems.

a. If a ground mat is used in conjunction with a system of radials, ensure that each radial is bonded to the mat.

b. In the event that local surface characteristics prohibit mat burial, lay the mat on the surface and stake it at frequent intervals to prevent shifting.

c. The primary consideration for the gauge of wire or thickness of expanded copper metal to be used in fabricating the ground mat depends upon the anticipated mechanical stresses.

3.3.3 Counterpoise

A system of conductors elevated above and insulated from the earth constitutes an antenna counterpoise which forms a large capacitance with ground. This counterpoise simulates a ground plane to stabilize antenna impedance. The following considerations should be observed for effective application of a counterpoise:

a. It must be placed directly under the antenna.

b. It must be scaled in size according to operating frequency. The size must be adequate to provide capacitance of a value that will have a low reactance at the operating frequencies, thus minimizing any potential difference between the counterpoise and ground.

3.4 ANTENNA FEED SYSTEMS

HF antenna feed systems must have low voltage standing-wave ratios and may be categorized as either balanced or unbalanced.

a. Balanced feed systems are comprised of open-wire parallel lines, with a nominal impedance of from 300 to 600 ohms, and impedance-matching devices as required.

b. Unbalanced feed systems are comprised of coaxial cable, with a nominal impedance of 50 ohms, and impedance-matching devices as required.

c. The VSWR should not exceed 1.1:1, for either a coaxial cable or an open-wire feed line, over the operating frequency band when the line is terminated in its characteristics impedance.

d. Detailed criteria on HF transmission lines and other antenna associated components are contained in chapter 6, and in reference 14.

3.5 ANTENNA SITING

Factors which must be considered in siting antennas are radiation hazards, environmental factors (topographical and electrical), real estate requirements and ground constants.

3.5.1 Radio Frequency (RF) Radiation Hazards

Careful attention must be given to site selection for transmitting antennas with regard to RF radiation hazards.

a. Hazards of Electromagnetic Radiation to Ordnance (HERO). Siting transmitting antennas in areas in which ordnance materials are located can create potentially hazardous conditions. Therefore, site approval with regard to ordnance materials is required in accordance with NAVFAC Instruction 8020.3 — "Site Approvals for Electromagnetic Wave Generating and Transmitting Equipment," 16 February 1968.

b. Hazards to Fuel. The exposure of fuel to RF radiation is a subject of discussion in NAVORD 3565/NAVAIR 16-1-529 — "Technical Manual, Radio Frequency Hazards to Ordnance, Personnel and Fuel," (U), and in NAVELEX 0101,103.

c. Hazards to Personnel. Safe exposure limits for the protection of personnel from the effects of RF radiation are discussed briefly in chapter 8.

3.5.2 Terrain Considerations

HF antennas should be located on reasonably flat ground. Areas with large concentrations of rock should be avoided since grading and construction problems are magnified by such terrain, and because non-uniform ground constants are likely to exist because of the soil dissimilarities.

Antennas should be sited so that obstructions such as buildings, tall metal structures, and mountains are not in the direction of propagation. The obstruction angle for a given wavepath must not exceed 5° (3° is preferred).

3.5.3 General Considerations

The following general considerations apply in locating HF antennas:

a. Fixed directional antennas, such as rhombics and LPA's (horizontal and vertical), should be sited so that their main beam does not radiate through other HF antenna arrays. This requires that they be located at the antenna park perimeter nearest the azimuth of the intended direction of transmission or reception.

b. Rotatable log-periodic antennas (RLPA's) should be grouped together where possible to reduce any detrimental effect that their supporting towers may have on vertically polarized antennas.

c. Higher frequency antennas, such as RLPA's and some conical monopoles, should be located as close as possible to the transmitter or receiver building to minimize coaxial line losses.

d. HF antennas for which spacing requirements are the same should be grouped together to conserve real estate.

e. In cases where land availability is critical, it is possible to locate a vertically polarized antenna within the area occupied by a rhombic antenna without sacrificing performance. In such installations, the vertically polarized antenna should be located near the center of the rhombic clear of the rhombic curtains, feed pole, and terminating resistance. The rhombic array in which the other antenna is located should have wood supporting structures, and guy wires should be broken up with insulators. Also the rhombic should have a lumped termination resistance in lieu of dissipation lines to afford adequate space for installing the vertical antenna.

3.5.4 Separation From Sources of Interference

Interference from sources of electromagnetic radiation, such as radio and radar transmitters, and noise from electrical devices are of concern in siting HF receiving antennas. In order to minimize the effects of this interference, receiving antennas should be sited in accordance with separation distances specified in table 3-1.

3.6 ANTENNA SEPARATION

Separation of HF antennas is an important factor that affects antenna performance. The criteria for separation are determined by the physical and electrical characteristics of the antennas and by the antenna application (transmitting or receiving).

3.6.1 Separation Requirements for Antennas of Unlike Function

HF antennas of unlike function (transmitting and receiving) should be separated by a minimum distance of 15 miles. If this separation is decreased serious degradation of the receive function may result due to interference created by the transmitters. This interference can be caused by adjacent-channel operation, harmonics, keying transients, and parasitic oscillations. Also, cross-modulation products can be generated in HF preamplifiers and receivers by strong RF fields, even though normal receiving frequencies are widely separated from the frequencies of such fields. Receiving antennas should be separated from transmitting antennas in accordance with the criteria in table 3-1.

3.6.2 Separation Requirements for Antennas of Like Function

The separation distance between any two antennas of like function (all receiving or all transmitting) can be determined from the following spacing criteria. All distances, unless otherwise noted, are based on the antennas lowest design frequency. The larger of the two distances in each case is used as the spacing distance. The points of measurement are between the reference points listed for each type of antenna (except rhombics).

Table 3-1. Receiving Antenna Separation Distances

SOURCES OF INTERFERENCE	MINIMUM DIST
High-power transmitter stations:	
Very low frequency	25 mi
Low frequency/high frequency	15 mi
Other transmitters not under Navy control	5 mi (see Note 1)
High-voltage power transmission lines 100 kV or greater	2 mi
Receiver Station power feeders	1000 ft from nearest Antenna
Airfields and glide paths:	
For general communications	5 mi
For aeronautical receiving at air station	1500 ft
Teletype and other electromechanical systems:	
Low level operation or installed in shielded room	No minimum
High level operation installed in unshielded room	
Large installation (communications center)	2 mi from nearest Antenna
Small installation (1 to 6 instruments)	200 ft from nearest Antenna
Main highways	1000 ft
Habitable areas (beyond limits of restriction)	1 mi
Areas capable of industrialization (beyond limits of restriction, see Note 2):	
Light industry	3 mi
Heavy industry	5 mi
Radar installation	(See Note 3)
Primary power plants	5 mi

NOTE 1: The following NAVELEX requirements also govern distances to non-Navy transmitter stations:
- (a) Signal from non-Navy station shall not exceed 10 millivolts per meter (field intensity) at Navy site boundary.
- (b) Harmonic or spurious radiation from the non-Navy station shall not exceed 5 microvolts per meter (field intensity) at the Navy site boundary.

NOTE 2: The restriction limit is the protective corridor i.e., that area between the outer limits of antenna field and the site boundary.

NOTE 3: Calculate using "Electromagnetic Prediction Techniques for Naval Air Stations," White Electromagnetics, Inc., Rockville, Md., NObsr 87466.

a. Rhombics. Rhombics should be separated 250 feet from other types of horizontally polarized antennas. The 250-foot distance is measured from the nearest radiating element of the rhombic antenna to the reference point listed for the other antenna. However, rhombics may be located immediately adjacent to other rhombics (including the sharing of common side and/or rear poles) as long as their radiators do not overlap.

Nesting a higher frequency rhombic inside its lower frequency complement (using a common rear pole) is permissible, and is encouraged, in order to reduce land requirements.

Vertically polarized antennas may be placed inside a rhombic as noted in paragraph 3.5.3.e.

b. Vee Antennas. Spacing requirements are the same as for rhombics.

c. Horizontal LPA. Space two wavelengths from the main lobe and one wavelength outside the main lobe, measured from the main supporting structure (midway between supporting structures for two-tower configurations).

d. Vertical LPA. Spacing requirements are the same as for horizontal LPA's.

e. Rotatable LPA. Space two wavelengths from horizontally polarized antennas. The separation requirement from a vertically polarized antenna is determined by the spacing requirement of the vertical antenna. In all cases, spacing must not be less than 150 feet.

f. Yagi. Space one-half wavelength measured from the center of the nearest radiating element.

g. Horizontal Doublet. Space one-half wavelength measured from the feed point.

h. Medium Frequency/Low Frequency Long-Wire. Space 500 feet measured from the feed point.

i. Inverted Cone. Space one wavelength measured from the antenna center.

j. Conical Monopole. Spacing requirements are the same as for inverted cones.

k. Sleeve. Space one wavelength measured from the sleeve element.

l. HF Vertical Radiators. These include vertical doublets and other discrete frequency antennas with a bandwidth of 10 percent or less at the center design frequency. Space one-half wavelength measured from the supporting structure.

m. Vertical Low Frequency Tower. Space 1000 feet from all HF antennas.

n. Sector Log Periodic. Space two wavelengths measured from the main supporting structure.

o. Sector Sleeves (90° and 180°). Space two wavelengths measured from the sleeve element.

p. Selectively Directional Monopole. Space 2 wavelengths measured from each monopole element.

3.7 REAL ESTATE REQUIREMENTS

The amount of land necessary for locating individual HF antennas is based on the following requirements:

a. Directional pattern desired

b. Polarization

c. Operating frequency (antenna size)

Land requirements for most types of HF antennas used in naval shore installations are tabulated in foldout 5-1. These stated requirements do not take into account antenna siting and separation criteria, both of which must be considered separately.

3.8 GROUND DIELECTRIC CONSTANTS AND CONDUCTIVITY

The ground dielectric and conductivity of any intended antenna location should be considered according to individual antenna requirements. As previously discussed in paragraph 2.6 the presence of ground affects the various types of antennas in different ways.

Once the site is selected for an antenna farm, only limited choices are available for location of individual antennas. Ideally, vertically polarized antennas should be installed in an area of high ground conductivity to provide a low-loss return path for ground currents. In actual practice, however, the importance of this is minimized because vertical antennas are usually constructed over a fabricated ground plane to ensure impedance stability and a low-loss return current path. Paragraph 3.3 cites the necessity for ground planes.

Horizontally polarized antennas erected at least one-quarter wavelength above ground do not require ground treatment to reduce dielectric losses or to stabilize impedance characteristics. The primary consideration for height of horizontal rhombics above earth is the useful radiation angle of the antenna. Assuming that the height requirement can be met, the other ground requirements can be satisfied if the surface is level at the antenna location and the ground conductivity is high enough to provide ground reflection for long-range transmission. An ideal location is one where a body of water extends for several miles in front of the antenna.

Ground constant values for many diverse types of soil are available in references 26 and 27 of appendix C. An abbreviated general guide for ground conductivity and dielectric constant is given in table 3-2.

Table 3-2. Typical Ground Constants

TYPE OF GROUND	REL DIELECTRIC CONSTANT	CONDUCTIVITY (MHOS/METER*)
Sea water	81	4.64
Good ground. Pastoral land with good soil	20	3×10^{-2}
Poor ground. Hilly country, moderate vegetation, urban districts	5	1×10^{-3}

*Conductivity in electromagnetic units, emu, is 10^{-11} times the conductivity in mhos/meter.